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BUREAU OF ENTOMOLOGY

FOREST INSECT INVESTIGATIONS

FIELD OBSERVATIONS ON MORTALITY OF WESTERN PINE BEETLE DUE TO FREEZING

by

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Table of Contents

Introduction - 1

Description of Area and Stand - - - - - - - - - - - - - - - -2

Problems - 2

Methods -2

Results- 3

- Composition of Infestation - - - - - - - - - - - - - - -3
- Air Temperatures- 3
- Amount of Brood Reduction- - - - - - - - - - - - - - - -4
- Area Extent of Brood Reduction- - - - - - - - - - - - - 5
- Other Factors Affecting Brood Reduction- - - - - - - - -5

Discussion - 6

- Methods- -6
- Results - 7
- Effects of Freezing on Present Brood - - - - - - - - - -9
- Possibilities of the 1933 Season- - - - - - - - - - - -10

Plans for Future Work - - - - - - - - - - - - - - - - - - - 10

Summary- -10

Figure I

FIELD OBSERVATIONS ON MORTALITY OF WESTERN PINE BEETLE BROOD DUE TO FREEZING

Introduction

Low air temperatures, sufficient to kill all stages of brood of the western pine beetle, Dendroctonus brevicomis Lec., are known to occur in many areas in which that insect remains one of the chief causes of death of its host plant, ponderosa pine (Pinus ponderosa Laws.). The reason for the escape of at least a considerable portion of the brood in those areas lies in the fact that the temperatures of the environment of the insects in the inner and outer bark of pine trees are higher than surrounding air temperatures, chiefly due to the insulating qualities of the bark. As a result, although some mortality due to low temperatures undoubtedly occurs in some areas every year, there are but few cases on record in which noticeable mortality has been found. Miller[1] cites Jaenicke's record of December 1924 at Bend, Oregon, in which air temperatures of from 20 to 25 degrees below zero caused a mortality of from 25 to 80 per cent of the brood. Relatively vague reports of brood reduction due to similar temperatures in the same general region in 1927 have been given the writer by local residents of the area.

Another definite record of the freezing of western pine beetle brood is available this year, due to the low temperatures of December 10, 11 and 12, 1932, in the Badger Unit of the Modoc National Forest, California. Fortunately the infestations of this area have been under observation since 1921; and no later than October 1932 an intensive survey of insect losses was made that resulted in figures indicating the presence of an epidemic infestation. Recommendations were made that the epidemic be subjected to control measures. These recommendations were adopted by the Forest Service and the Pickering Lumber Company; $12,000 was allotted by the former and $10,000 by the latter for treatment of the infestation.

The writer and E.F. Wohletz spent from December 1 to 11, 1932, in the field aiding in the organization and technical phases of the project, and during that time collected several bark samples for use by the Bureau of Entomology in determining the predator population in the bark. Examination of these samples in Berkeley revealed 100% brood mortality due to freezing; but as the brood had experienced unusual exposure to low temperatures, additional samples were requested from the Forest Service men working on the control project. These arrived on December 27, and counts showed 100 per cent mortality in three of the four samples and 50 per cent kill in the fourth.

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[1] Miller, J.M. High and Low Lethal Temperatures for the Western Pine Beetle. Jour.Agr.Res., 43,4:303-321, 1931.

Due to the unusual nature of this brood reduction, some doubts remained that the results represented general conditions, for critical factors might have been introduced during shipment. Accordingly a field trip and sampling of the entire project was undertaken during the period December 28 1932 to January 1 1933. The results of that examination are presented in this report.

Description of Area and Stand

The project area contains from 44,000 to 47,000 acres in Townships 43 and 44 North and Ranges 8 and 9 East, Mt.Diablo base and meridian. Ownership is distributed chiefly between the U.S. Government and the Pickering Lumber Company. The stand is pure ponderosa pine, mature and overmature, and the topography is relatively level, the area being on a sort of plateau of from 4,600 to 5,200 feet elevation. Drainage is to the northwest into Tule Lake.

At the time of the examination approximately 10 sections had been subjected to control, and an additional 8½ sections had been spotted for infested trees.

Problems

The points to be determined by the examination were as follows:

1. Composition of infestation in the project area,
2. The air temperatures during the period of low temperatures,
3. The amount of brood reduction in terms of brood,
4. The area extent of brood reduction; i.e., local or general,
5. The relationships, if any, between brood reduction and bark thickness, tightness of bark on the tree, stand density, exposure and height of brood above ground.

Methods

Felled trees were examined in the area in which control was being done, and samples were taken from various heights on the trunks. In addition, the spotting crews of the control project were utilized in collecting samples on selected courses designed to give a representative coverage of the project area. All samples taken by the spotting crews were from about breast height, and as even a distribution as possible was secured between north and south exposures, brood stages, and area covered by the courses. Brood counts were made in the field of a sufficient number of samples to determine whether or not the period of shipment introduced factors leading to significant differences in the results, and the remainder of the samples were examined in the laboratory at Berkeley.

Records taken for each sample included exposure (north or south), bark tightness, foliage phase of the tree, stand density and location of the sampled tree. Bark area and thickness were measured when the brood was counted, and records were taken of all living and dead insect forms found in each sample. In all 138 samples were collected and counted, and 133 of them yielded data. Information concerning the status of the control project as of December 30 1932 and the locations in which the samples were taken is given in Fig. I. The data secured from the bark counts are in the several tables given below.

All tree-form records of trees on the controlled area that had been treated were examined and analyzed to furnish data regarding brood stages and composition of the infestation. Although all these records were taken from sections in the eastern and northeastern portions of the project area, it is believed that the information is typical of the entire project area and that the results may be applied directly. All infested trees were spotted on this project, which means that the figures do not give a distorted picture of the composition of the infestation.

Results

Composition of Infestation

The 430 tree-record forms examined showed the composition of the infestation to be as follows:

Insects and Stages	% Total Infestation
Miscellaneous insects, mostly mountain pine beetle and flathead borers	19.7
D.brevicomis, parent adults and eggs	13.2
" less than half-grown larvae	25.8
" more than half-grown larvae, pupae and new adults	41.3

Air Temperatures

Fortunately, in October 1931 the Bureau of Entomology established a weather-recording apparatus at the Pickering Portable Mill, which is within the project area. Records from a hygrothermograph are available for the period during which the critical temperatures occurred. Unfortunately, however, the machine had not been set sufficiently high to record the extremely low temperatures of the night of December 10, and on the morning of the 11th the pen was found to be riding the lower rim of the recording cylinder. However, where possible the air temperatures have been calculated; and although it is believed that they are above the actual temperatures, the following list gives the record as accurately as it can be secured from the data obtainable:

Temperatures at Pickering Portable Mill, Hackamore, Calif.

December Hour	9 Thursday	10 Friday	11 Saturday	12 Sunday	13 Monday
2 a.m.	+13	-3	-15c	-17	-16
4 "	+17	-4	-16c	-16	-12
6 "	+18	-3	-18c	-19	-15
8 "	+14	-3	-14c	-6	-15
10 "	+13	+5	0	+3	+8c
Noon	+12	+7	+4	+12	+21
2 p.m.	+10	+6	+3	+9	+19
4 "	+7	+3	0	+7	+15
6 "	+6	0	-6	-2	+6
8 "	+4	-7	-13	-7	+1
10 "	-1	-12c	-16	-11	-3
Midnight	-2	-15c	-17	-16	-6
Mean	+9.6	-2.7	-9.5	-5.3	+1.6
Maximum	+17	+7	+4	+12	+21
Minimum	-2	-15c	-18c	-19	-16

c=approximate temperature

No data are available to make it possible to calculate the probable bark temperatures during this period. As bark temperatures are those that will affect the brood stages, this phase of the problem is one that it would be desirable to investigate at earliest convenience.

Amount of Brood Reduction

The 133 effective samples analyzed for dead and living brood and dead and living insects not western pine beetles gave the following general mortality figures:

Insects and Stages	No. Individuals		
	Living	Dead	% Dead
Western pine beetle, all stages	2,531	4,584	64.4
do parent adults	61	130	68.1
do eggs	177	148	45.5
do less than ½-gr.larvae	661	1,517	69.6
do more do	1,629	2,764	62.9
do pupae	0	1	100.0
do new adults	3	24	88.8
Mountain pine beetle, all stages	5	6	54.5
do parent adults	0	2	100.0
do larvae	5	4	44.4
Flathead borers, larvae	8	7	46.6
Ips emarginatus, adults	3	1	25.0
Enoclerus larvae	1	12	92.3
Temnochila "	4	14	77.8
Roundhead borer larvae	8	2	20.0
Aulonium longum adults	55	8	12.6
do larvae	23	13	36.1
Hypophloeus substriatus adults	9	1	10.0
Plegaderus nitidus adults	4	0	0.0

Area Extent of Brood Reduction

The data from the 133 samples show conclusively that the mortality due to freezing, although it may have been more severe in certain rather local areas, was general in its action. This will probably be an important factor in the 1933 infestation on the project area, as the effects of the freezing will be felt outside as well as inside the area.

Other Factors Affecting Brood Reduction

The relation of bark thickness and brood mortality of the larval stages of the western pine beetle are brought out in the following table:

Bark Thickness Inches	No. Samples	No. Individuals Living	No. Individuals Dead	% Mortality
¾-1	6	1	202	99.5
1-1¼	25	401	957	70.4
1¼-1½	38	242	1,367	84.9
1½-1¾	14	232	530	69.6
1¾-2	15	500	610	54.9
2-2¼	14	733	477	39.4
2¼-2½	2	98	137	58.2
2½-2¾	1	53	3	5.4
Totals and Averages	115	2,260	4,283	65.5

There appears to be a rather definite relation between bark thickness and brood mortality.

Field observations seemed to indicate that definite relationships existed between brood reduction and tightness of bark, density of stand, exposure and height of brood above ground. Although it was realized that the effects of no one of the factors could be isolated entirely and measured, it was expected that general indicatory trends would be revealed by appropriate grouping of the data. These expectations were not fulfilled except in the case of the relationship of exposure to brood reduction. Exposure on the individual trees apparently did influence brood mortality. Seventy samples taken from the north sides of 70 trees averaged a 66.1% reduction, and 88 samples from the south sides of the trees averaged a 62.2% reduction. However, these results are not definite enough to be considered as conclusive evidence.

In the examination of the relations existing between density of stand and brood reduction, 39 samples from open stands showed an average reduction of 58.4%; 99 samples from normal stands showed a 64.8% brood reduction, and 11 samples from heavy stands showed a 59.8% brood reduction. These figures do not seem to be indicative of any definite trend or effect. Similarly, height above ground could not be proven definitely to have an effect on brood reduction. Naturally the bark would become thinner on the upper bole of a tree and would result in greater mortality. However, this could not be proven from the figures secured by brood counts of a series of samples from nine trees. In addition, no correlation could be discovered between tightness of bark and brood reduction. Naturally the younger and more resistant stages would reside in the tighter-barked trees, which would result in lower mortality figures. This could not be proven, although attempts were made using all stages of brood as well as single stages, such as the half-grown larval stage, which are to be found in tight-barked as well as loose-barked trees.

Discussion

Methods

The sampling of the project area may be considered sufficient as far as area distribution is concerned (v. Fig. I). The number of samples is the equivalent of sampling all trees on somewhat less than two sections, which gives more than a 2% sample of the area on a tree basis. It is believed that the selection of trees for sampling and the use of samples at breast height will give conservative results and mortality estimates that may be considerably lower than actual mortality.

In selecting trees for sampling, the greater portion of the samples came from courses similar to ordinary spotting runs, and thus may be considered random. However, in the second day's work the spotting crews were instructed to pay particular attention to green and tight-barked trees. It was immediately noticeable that the living brood in these samples was much more in evidence than in the samples taken at random, and this was substantiated by the fact that mortality in the 33 samples selected during the second day averaged 53.5%, which is considerably below the average of all samples. A special examination was made in order to determine if this lower mortality was peculiar to the area instead of the type of tight-barked, green or partially

faded tree that was selected. As far as could be determined, the difference could not be attributed to the area. Thus we may consider the effect of the second day's sampling on the final results to be toward the lowering of mortality figures below the actual.

Results

J.M. Miller (loc.cit.) has published the results of a considerable amount of laboratory work with the effects of high and low temperatures on western pine beetle brood. It is important that we compare his results with those of the field examination. He (p.320) summarizes his laboratory results as follows:

" . . . Mortality of larvae follows freezing when bark temperatures are lowered below 0 degrees F. Partial mortality occurs at zero in broods which overwinter in the yellow pine belt of the Sierra Nevada region; mortality at -5 degrees F. exceeds 60%, and practically no larvae survive at -10 degrees. Temperatures within the range from 0 to -10 degrees are consistently critical, regardless of the rate at which the temperature of the bark is lowered or warmed back from sub-zero to normal temperatures; complete mortality develops within this range regardless of whether the larvae are actively developing or dormant at the time the bark temperature is lowered to the critical points.

"High mortality of the pupae occurs at temperatures between 5 and -5 degrees, and is complete at -8 degrees F.

"High mortality of the adults occurs between 12 and 5 degrees F. and is nearly complete at 0. . . . .

"Broods which overwinter in regions where the minimum winter temperatures are below zero apparently develop greater resistance to cold than in regions with mild winter climates. Larvae which had passed through the overwintering condition at Coeur d'Alene, Idaho, where air temperatures of -10 degrees F. had been reported, developed high mortality when bark temperatures were reduced through the range from 0 to -10 degrees. However, about 25% survived a temperature of -10 degrees. Mortality was practically complete at -18 degrees. The difference between low temperatures withstood, owing to the influence of regional conditions, apparently does not exceed 10 degrees.

"The outer bark on standing infested trees cools down much more slowly than the surrounding air, and does not reach the minimum temperatures recorded by weather thermometers. Records obtained at Coeur d'Alene, Idaho, during two periods of sub-zero weather, indicate that minimum bark temperatures are 10 to 12 degrees higher than minimum air temperatures."

When we examine the results of the field work it is almost impossible to do any more than guess the lowest bark temperature that occurred. On the basis of the fact that there may be a 10 to 12 degree difference between bark and air temperatures, we may consider that it was possible for the bark to reach a temperature of -7 degrees F. during the time of the actually recorded temperature of -1

degrees. However, due to the fact that the low temperatures lasted for three days with no protracted period of temperatures much above zero, it may be that the bark reached much lower temperatures, for the bark would not warm up much more quickly than it cooled down, and the nearly continuous sub-zero temperatures may have brought the actual bark temperature below -7 degrees F.

As air temperatures in the Modoc region often go below zero in the winter, we may consider the western pine beetle brood to have a greater resistance that may approach that mentioned by Miller for brood from Idaho. Under those conditions of resistance, bark temperatures of -7 degrees F. would, on the basis of Miller's laboratory work, result in approximately the mortality secured.

The mortality figures of larval stages secured from the field examination agree fairly closely with Miller's results, if bark temperatures did reach -7 degrees. The pupal mortality cannot be considered, for the single individual of that stage that appeared in the counts cannot be considered a fair sample. Mortality in the eggs also agrees fairly closely with Miller's results. The 88.8% mortality of new adults secured in the field approaches Miller's laboratory results. The mortality of 68.1% in parent adults, however, indicates greater resistance.

In spite of the limitations imposed by the small size of the samples, it is of interest to note the effects of low temperatures on other insects that are commonly found under the bark of infested ponderosa pine.

An observed mortality of about 25 to 30% in mountain pine beetle broods reached 44.4% in the few counts made. It is obvious that the mountain pine beetle has greater resistance to cold than the western pine beetle.

Observed mortality of about 30% in flathead larvae was found to be somewhat greater in the counts. Apparently this insect also has greater resistance to low temperatures than the western pine beetle.

It is interesting to note that although the samples are small both Enoclerus larvae and Temnochila larvae, which are predatory species, show less resistance to cold than does one of their hosts, the western pine beetle.

Other secondary insects, including roundhead borer larvae (probably Acanthocinus spectabilis), Aulonium longum adults and larvae, Hypophloeus substriatus adults and Plegaderus nitidus adults, all show greater resistance to low temperatures than the western pine beetle.

Effects of Freezing on Present Brood

If we compare the relative effects of the freeze and the effects of normal control operations, several points indicate a probable balance in favor of the freeze. The effects of the freeze will be widespread, and will not be limited to the project area. This will probably result in fewer individuals available for infiltration from outside sources. All trees have suffered a certain mortality due to freezing this year, but its measurement will need a determination of reinfestation during 1933.

In any control operation trees are missed. This means 100% of the brood in those trees is available for reinfestation, with allowance for a small natural mortality. In addition, practically 100% of the brood outside the treated areas is available for the following season, and unless adequate entomological-unit boundaries exist, infiltration into the treated area will be inevitable. The brood that is missed will be for the most part in the younger stages. This will result in a reduced early-season infestation, and consequent reduction of time during which the summer broods will be actively engaged in infestations outside the host trees of the previous winter.

In the case of freezing, a portion of the brood in all trees will be killed. The more mature broods will suffer the most, and thus there will be less early-season infestation. Conditions during the following season will be similar to those produced by control measures. In addition, there will probably be greater mortality due to birds in the Modoc this year. During the field examination woodpeckers were unusually active; and although driven out of a control area by the lack of food, they will find the same conditions outside and inside the control area this year, due to the effects of the freeze, and will beforced to concentrate on those trees containing the more advanced brood that has survived. It is felt that the concentration of their activities will result in a greater effectiveness.

Of all the brood stages, the parent adults will be of little value in next year's infestations. Similarly the pupal forms have probably all been killed, and the new adult stages so reduced in numbers as to be realtively ineffective. If mortality figures for parent adult and egg stages are grouped, and the more than half-grown larval, pupal and new-adult stages grouped, the effective reduction of the western pine beetle brood and its probable status in the infestation at the start of next season may be calculated. If an arbitrary mortality figure of 30% is given to other insects, chiefly mountain pine beetles and flathead borers, we find that of the original infestation, of which 80.3% consisted of western pine beetle brood, but 42.9% remains. Of this, basing percentages on the original infestation, 13.8% will be caused by other insects and 29.1% will consist of western pine beetle brood. Thus the composition of the infestation has been changed from 19.7% other insects and 80.3% western pine beetle to 32.9% other insects and 67.8% western pine beetle brood. A 57.1% general reduction of broods of all primary insects has been secured.

Possibilities of the 1933 Season

The effects of the freezing can be effective during 1933 chiefly through the destruction of the early-season broods and resultant shortening of the season during which the insects will be active outside their present host trees. One condition that will probably prove of benefit to the western pine beetle brood is the reduction secured on predator broods, which was greater than that on western pine beetle brood. The development of the infestation during 1933 will, however, depend largely on growing and climatic conditions. If precipitation during the remainder of this winter does not average considerably more than it has to date, the stands are not going to be in a better condition to resist attack. In such a case the effects of the freezing will be merely a setback to the progress of the epidemic infestation, and the broods may make up all or more than they lost this winter during the 1933 season. The same possibility would exist of a reduction secured by a control project. If unfavorable conditions for brood development obtain during the 1933 season, they may substantially reduce the epidemic. The future of the stand and of the infestation rests largely on future environmental conditions. The effects of the freezing may be those of a temporary setback or may be factors that will present the 1933 season with a reduced and less vigorous population of western pine beetles upon which unfavorable environmental conditions may work to greater advantage.

Plans for Future Work

Plans have been made to continue studies of the effects of the 1932 freeze on subsequent infestations. Due to the inclusion of two Bureau of Entomology plots in the treated area, data will be available for a comparison of the effects of the freeze alone and when supplemented by control work. In addition it is planned, by means of brood counts from samples to be obtained by cooperators this winter and emergence counts to be made during the coming season, to determine the extent and effectiveness of the freezing temperatures in other areas. Equipment is planned for the determination of bark temperatures in relation to exposure to air temperatures; and from this record it is hoped to provide a means for linking winter brood mortality with weather bureau records of the future.

Summary

Recent low temperatures in the Badger Springs area of the Modoc National Forest resulted in considerable mortality of western pine beetle broods. An average mortality of 64.4% of all stages was secured from samples collected in the project area, and on that basis the active control project on the area was terminated.

The following salient features were brought out by field examinations:

1. Three days of low temperature occurred, during which the highest temperature recorded on the hygrothermograph was +12 and the actual lowest recording was -19;

2. Samples and brood counts showed the mortality of western pine beetle brood to be 64.4% of the total of all stages, and the brood reduction was found to be general throughout the project area;

3. A relationship was found to exist between brood reduction and thickness of bark. Some evidence showed a greater brood reduction on the north side of trees. No evidence except that provided by general field observations indicated relationships between brood mortality and tightness of bark, density of stand and height of brood above ground;

4. Mortality figures appear to indicate that bark temperatures reached about -7 degrees F. Mortality figures for eggs, larvae and new adults agreed fairly well with Miller's laboratory results. The sample of pupal stages was too small to lead to conclusions, and parent adults showed greater resistance to cold than new adults;

5. Mortality figures on larval stages of predators show greater reduction than was secured in the brood of the western pine beetle. Several other species of insects, secondary in nature, showed greater resistance and less brood reduction than did the western pine beetle;

6. Comparison of the effects of the freeze as compared with a normal control operation will have to await the results of the coming season. The future of the 1933 infestation rests with future environmental conditions. The brood reduction caused by the freeze may constitute only a temporary setback to the epidemic infestation, or may result in a more favorable setting for future unfavorable environmental factors.

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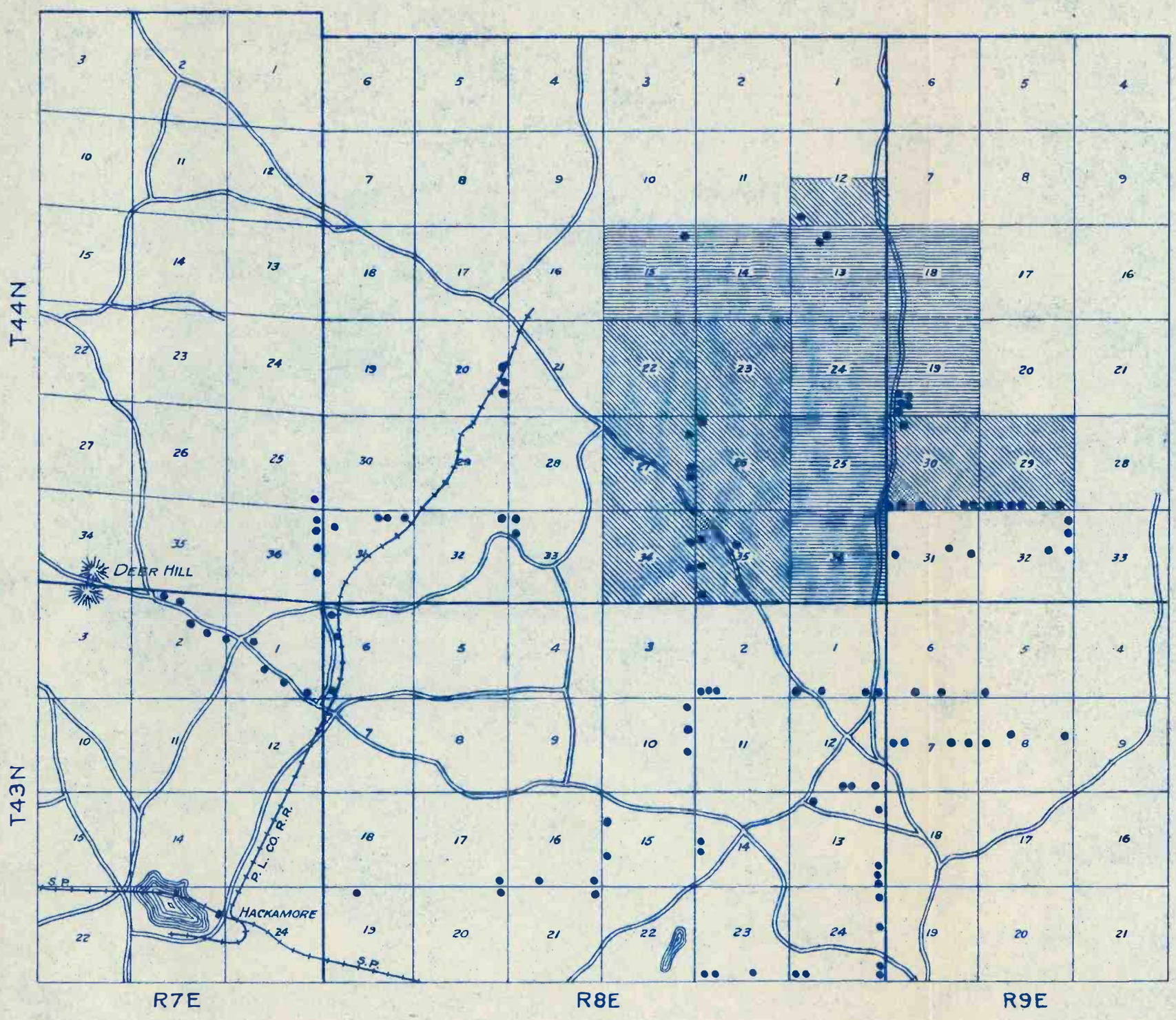

FIELD INVESTIGATION OF FREEZING

LOCATION OF SAMPLES

MODOC NATIONAL FOREST CALIFORNIA

▨ SPOTTED – NOT TREATED

▤ SPOTTED AND TREATED

• TREES SAMPLED

Fig. 1

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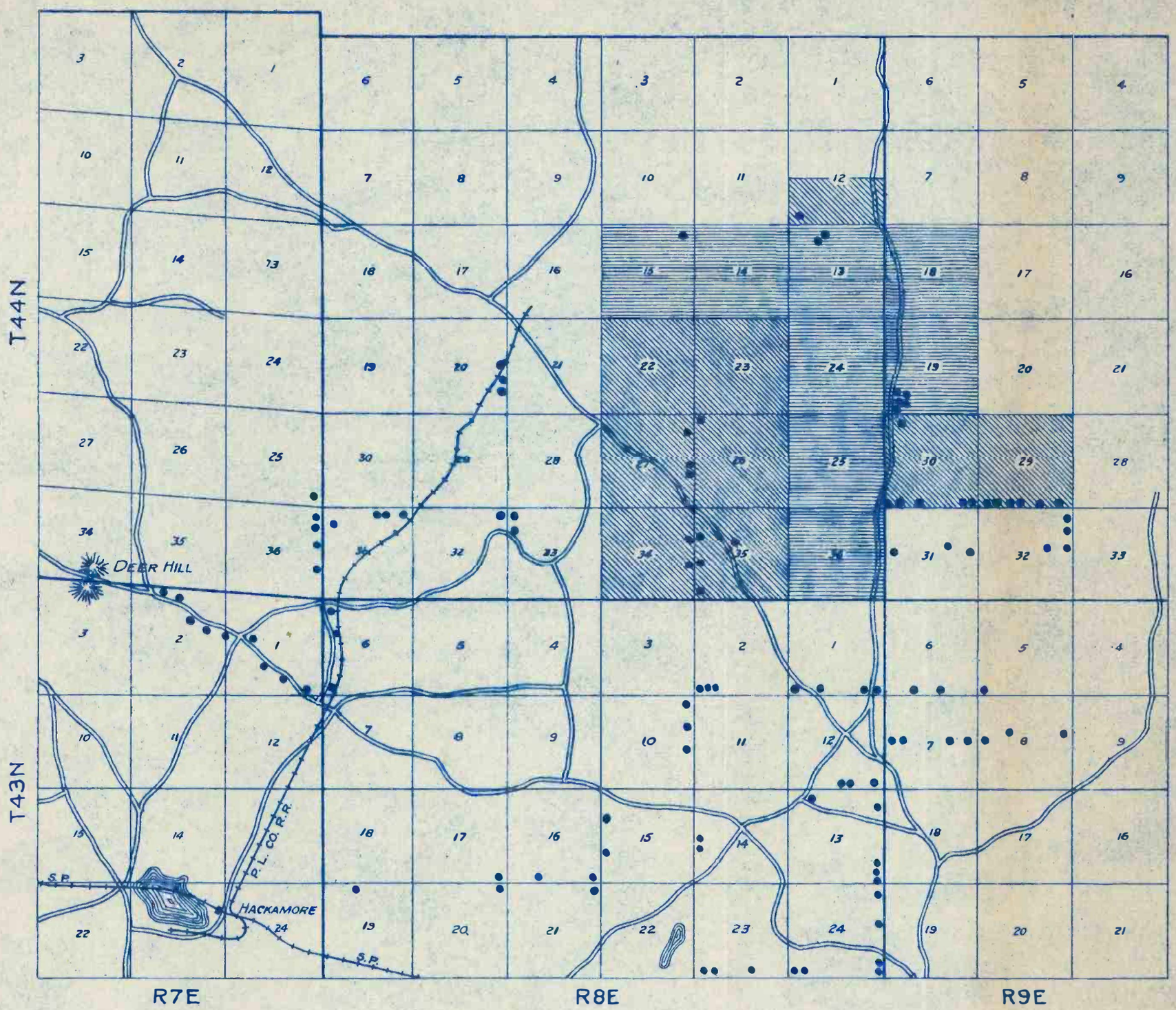


FIELD INVESTIGATION OF FREEZING

LOCATION OF SAMPLES

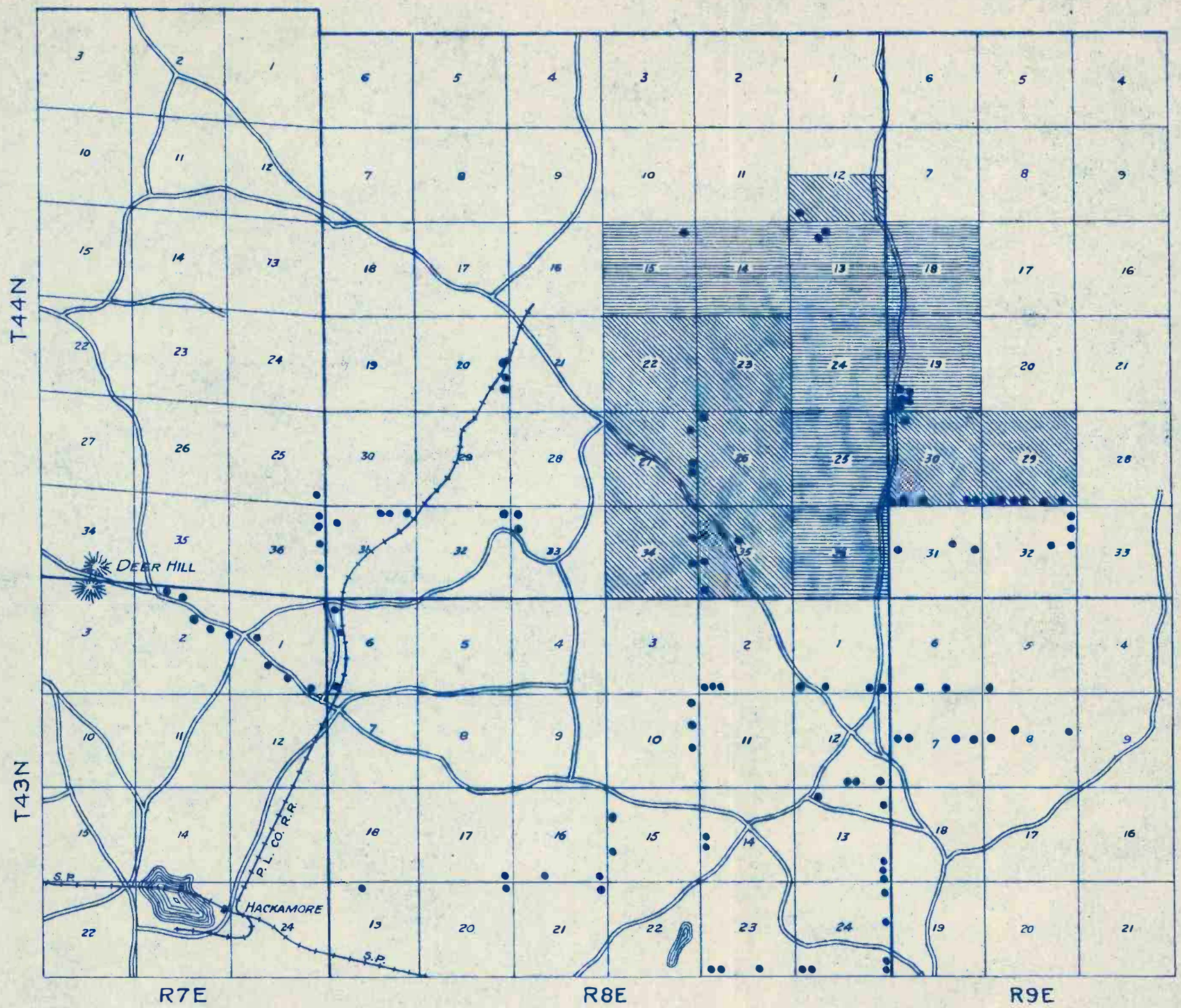
MODOC NATIONAL FOREST CALIFORNIA

Spotted – Not Treated

Spotted and Treated

Trees Sampled

Fig. 1



FIELD INVESTIGATION OF FREEZING

LOCATION OF SAMPLES

MODOC NATIONAL FOREST CALIFORNIA

SPOTTED – NOT TREATED

SPOTTED AND TREATED

• TREES SAMPLED

Fig. 1